Brampton Mining

ELECTRICITY UTILIZATION:

TRENDS IN UNDERGROUND MINING

BY

BRAMPTON MINING COMPANY LTD.

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Brampton Mining

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ELECTRICITY UTILIZATION:

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BY

P. WHITE, P.ENG

ABSTRACT

The federal Department of Energy, Mines and Resources (EMR), through the Canada Centre for Mineral and Energy Technology (CANMET), is actively involved in encouraging the development of mining technology for the Canadian hard rock mining industry. This document is one of a series of contract reports prepared to analyze specific potential equipment applications in hard rock mines. The contents of this report have been based on site visits and discussions with selected mines, equipment manufacturers and mine inspectorates from across Canada.

This report presents the results of the investigations regarding the increased underground application of electrically powered equipment. A synopsis of current energy utilization practices in underground mines is included, with detailed reference to the various uses of electricity. Equipment and operations which use or have potential for using electricity are discussed. The possibility of increased electrification is examined from the perspectives of safety, technical feasibility and economy.

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1.0 INTRODUCTION

The Federal Department of Energy, Mines and Resources (EMR) aims to ensure the effective use of Canada's energy and mineral resources. This includes stimulating the development of new mining technologies and transferring these technologies for use by operating mines. The Canada Centre for Mineral and Energy Technology (CANMET) is responsible for contributing to the objectives of EMR by conducting research in the energy and minerals fields. The minerals research program includes activities in technology development, as well as in resource determination, health and safety, processing technology and other areas.

One CANMET project within the mineral technology development sector involves the investigation of new mining technologies for underground hard rock mining operations. This project is comprised of a number of phases and is intended ultimately to promote the further development, by Canadian firms, of mining equipment for the underground hard rock mining industry, to improve productivity and performance, and to reduce the costs of mining underground orebodies.

It is expected that new techniques and equipment will not only increase safety but will provide improved economies of underground hard rock mining. The implementation of new techniques could also revolutionize the requirements for mine development, thus eliminating many existing unit operations commonly found in underground mining.

The first part of this project has been previously completed and consisted of a literature search and a questionnaire survey of mining operations to identify the most promising areas where equipment development could influence mining operations and mine design. The results of this initial work indicated that the following areas held the most likely potential for benefit to hard rock underground mining operations in Canada:

a) Increased use of electrically powered equipment.
b) Application of high capacity or continuous ore loading and transportation systems.
c) Automation of underground equipment.
d) Development of high speed mechanized excavation methods.
e) Application of remote monitoring and control systems.
f) Retaining waste rock underground.

The second part of the project, which is the focus of this series of reports, involved the analysis of the preceding potential equipment applications in hard rock mines, based on visits to selected mines, equipment manufacturers, and mine inspectorates across Canada. These site visits are the key aspect of the second phase of this project to ensure that the analysis and evaluations of the potential equipment applications are based on comments and ideas from actual mine operators who are daily faced with the tasks of hard rock mining.

This report summarizes information pertaining to the increasing use of electrically powered equipment in underground mines as a substitute for diesel and compressed air powered equipment. A summary description of current energy usage at underground mines is presented and the potential for increasing electricity usage is assessed for different mining methods.

Those operations which have potential for electrification or for the use of hybrid power systems are identified. The use of increased electrification is assessed from the point of view of safety, economics and mine design, based on comments from the operating mine staffs who were visited. The availability of electrical supply capacity to meet the potential requirements, as well as the conceptual design aspects of new equipment are reviewed.

Study methodology included the preparation of questionnaires to obtain statistical information and operator opinions from existing operating mines. Mine operators provided descriptive information on electrical distribution systems and consumption data for electricity, diesel fuel, heating oil and propane. Additional relevant information included underground diesel fleet size, where applicable, as well as mine ventilation air flow rates and compressed air consumption.

The opinion survey solicited comments and judgements regarding the perceived commercial feasibility of alternative equipment development scenarios for a number of discrete mine operations. Through both discussion and underground visits at mine sites across Canada, a concensus was established regarding potential applications for new types of equipment.

Field visits were made to fifty operating mine sites for discussion with mine managers, supervisors and technical staff. In addition, meetings were held with mining contractors, mines inspectorate personnel, union representatives and public utilities. Numerous equipment manufacturers and suppliers made significant contributions to this project.

The response to this project from all sectors of the mining industry was very positive. The contributions of time, interest and experience on the part of many individuals are acknowledged by the author.

2.0 SUMMARY

The use of electricity in underground hard rock mines accounts for the majority of all energy requirements by underground mining operations. The trend established by newer mines is to increase the substitution of electrically powered equipment for the older pneumatic tools used throughout the industry for so many years. Similarly, older mining operations are relying on more electrically powered machinery in order to overcome the difficulties in providing adequate ventilation for diesel powered units.

A typical underground mining operation uses between 40-60 kilowatt-hours per tonne of ore produced, excluding the power required for mineral processing. Analysis of the available data showed generally poor overall correlation between energy utilization and mining method, rate of production and type of mining equipment. Individual uses of electricity did show definite correlations by type of mining operation.

It is concluded that considerable potential does exist for optimization in the use of electrical energy, as certain mines consistently demonstrated lower than average energy utilization than others. In a few cases, the reported data suggested that mine management did not appreciate the degree to which their electricity utilization was significantly higher than normal.

At many mines, the mine operators did not have access to data concerning the distribution of electrical energy consumption within their mining operation. Although they knew in dollar and energy terms the total monthly utilization, little effort was expended in determining just where and how the electricity was used. More importantly, very few mines monitored the usage trends or established energy budgets as targets for energy conservation and cost reduction measures.

The role of electrically powered equipment will increase over the coming years as mines attempt to use more powerful equipment for mining tasks than the pneumatically driven drills and machines currently in use. Large mines will increasingly turn to more sophisticated machinery that will utilize electric and electronic components to control and optimize equipment performance. Smaller mines, within the space limitations of narrow orebodies, will move gradually towards the electrification of manually controlled equipment in order to achieve greater performance than can be obtained with the use of compressed air-driven machines.

The role of monitoring and controlling computer-based equipment is an integral aspect of the increased electrification of mining equipment. Through the use of remote sensing and control techniques, mining activities can be extended beyond the existing manhour limitations per working shift.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

The physical appearance of mines, as well as the mine design approach will remain dominated by the orebody configurations and ground conditions. The machinery that will be used within the mine openings will change, however, to concentrate greater forms of energy on mining tasks than is possible using hand-held machinery. The role of mine planning will increasingly be concentrated on the sequencing of activities and the interdependency of events in order to increase the rate of production from individual working places.

The use of electrically powered and hydraulically operated machinery will gain wider acceptance in hard rock mines, as has already occurred in coal and potash mines. Although the types of hard rock mining machines will follow the drill-blast-muck cyclic approch, the use of more powerful energy sources will be instrumental in increasing the level of machine performance and manpower productivity.

3.0 CURRENT MINING PRACTICES

3.1 ELECTRICAL DISTRIBUTION SYSTEMS

The majority of Canadian mines receive hydro-generated electrical energy from provincial utility power grids. Eastern provinces have extensive electrical transmission systems connected to all major established mining camps. Most power utilities have recently undertaken expansion programs which provide a surplus of electrical generating capacity.

Mines located in remote areas are not serviced by utility networks and rely primarily on diesel generated power. These areas include the interior of Newfoundland, far northern Ontario, Manitoba north of Lynn Lake, British Columbia north of Fort St. John, Yukon and North West Territories. The economy of utility generated power is illustrated in Table 3.1 for a typical 1000 tpd underground mine, assuming a monthly power consumption of 450,000 kilowatt hours and a 1000 kilowatt utility demand charge.

Table 3.1 - ELECTRIC POWER SYSTEMS COST COMPARISON

Item	Utility Power	Diesel Power
Direct Cost of Energy		
(¢ per kWhr)	4	21
Capital Costs:		
Utility Power		
Pole Line Cost per km	$35,000	
Primary Substation	$50,000	
Diesel Power		
Monthly Rental		$ 25,000
Purchase Cost		$350,000

As can be seen from the preceding table, the cost for on-site diesel generation of electric power is five times greater than the cost of utility power. However, the economic equation for determination of the most suitable power source will depend upon the estimated project life and cash flow projections. In addition, technical considerations such as the type of terrain to be crossed by incoming power lines and the required power capacity will influence the actual cost parameters.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

A few mining companies that have been in production for several decades receive power from company-built hydro-generating stations. Inco at Sudbury, Hudson Bay Mining & Smelting at Flin Flon, and Sherritt Gordon at Lynn Lake built hydro-generating plants during the years when utility power distribution systems were not available, or did not have sufficient supply capacity for mining requirements. The majority of these company-built power stations have now been assigned to provincial utilities under the provisions of recent electricity supply agreements.

Some mining operations, mostly located in British Columbia, have ancillary hydro-generating stations that provide a base load power supply at costs of less than 1 ¢ per kWh. These installations typically feature a small dam to impound snow-melt water in a creek bed or lake, and a small diameter penstock directing water flow to a pelton wheel turbine generator. These installations rarely have sufficient capacity to provide more than a portion of the electrical requirements for mine operations, but the cost effectiveness of the limited quantities of electricity produced are significant.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

Until the introduction of underground mobile mining equipment in the late 1950's, most mines relied primarily on battery-driven or compressed air-operated equipment for mine development and production. As a result, the majority of electrical energy was consumed on surface by hoists, compressors and surface fans. Underground electrical power was used primarily for shaft station lighting, mine pumps and battery charging.

As a result of these practices, most of the mines brought into production a number of years ago required only 600 volt underground power cables of limited capacity to satisfy the mine power requirements. Any of those mines that are still in production are faced with the upgrading of underground power feed cables to enable the substitution of electrically-operated equipment for compressed air-powered equipment.

In addition, a number of mines in Northern Ontario were constructed using 25 cycle electrical power. Despite the subsequent introduction of 60 cycle power, many mines remain on 25 cycle power due to the high costs for converting existing infrastructure and equipment.

When these mines require the installation of new electrical equipment, one of two options must be selected:

a) Provide 25 cycle motors and motor controls.

b) Provide 60 cycle power to conventional equipment.

The selection of either option is dependent upon the economics of each specific situation.

Approximately 15 percent of underground mines distribute surface and underground power between major substations at 2300 volts, this being typical of many of the older mines initially constructed without the advantage of utility power. A further 60 percent of underground mines distribute power at 4160 volts, this being typical of more recently constructed mines with reasonable access to utility power grids.

The remaining mines distribute power between major substations at 13,800 volts (13.8 kV). These mines are typically the more recently constructed large scale operations with long power distribution routes. In these cases, the size of the total connected load and otherwise excessive power line losses warrant the installation of larger transformer installations.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

The power utilities distribute electrical power along major transmission lines at voltages of 230 - 500 kV. The utility-supplied line voltage feeding individual minesites is usually reduced to between 12 kV and 115 kV by the utility before reaching the main incoming transformer station provided by the mining company.

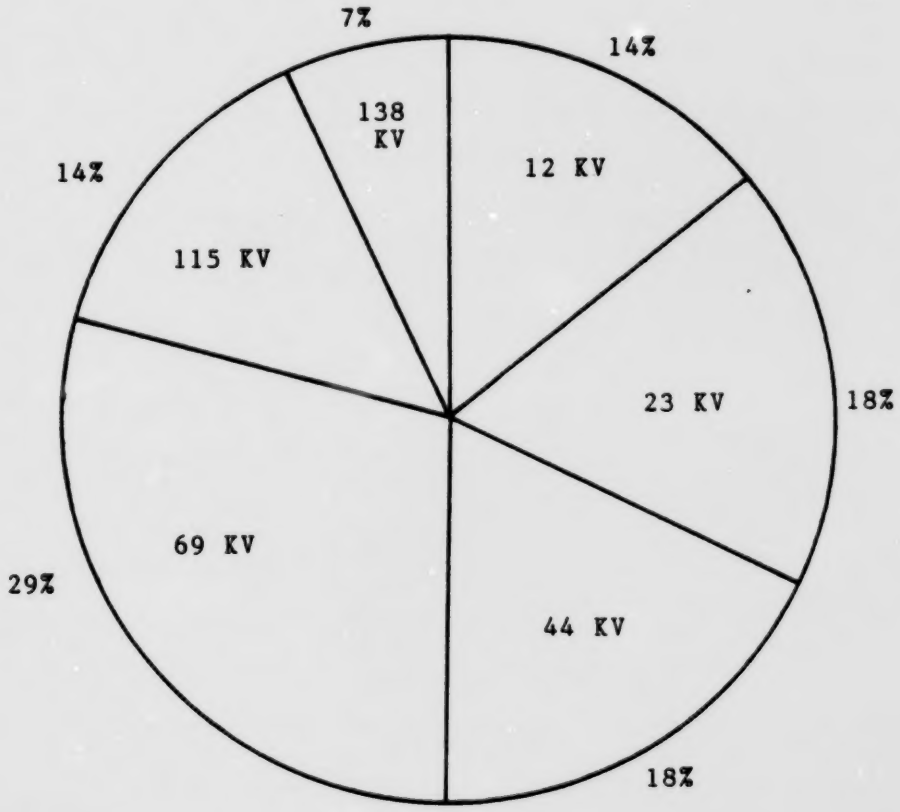
Approximately 29 percent of underground mines receive incoming power at 69 kV. A further 64 percent of underground mines receive power at either 115 kV, 44 kV, 23 kV or 12 kV in approximately equal proportions. In addition, a few mines are supplied power at intermediate voltages, usually below 44 kV. The distribution of incoming electrical voltage to underground mine sites by major voltage classifications is shown on Figure 3.1.

The determination of incoming supply voltage is primarily a function of the existing power utility transmission voltages in use at the time of the original mine construction. The design of a long transmission line serving a single customer usually reflects the economies of line construction at the time of installation. In areas with established transmission systems in place, the available line voltage is usually provided.

Figure 3.1

INCOMING ELECTRICAL VOLTAGE

TO UNDERGROUND MINE SITES



3.2 ELECTRICAL ENERGY UTILIZATION

The consumption of electrical energy in underground mines ranges from 20 to 70 kwh per tonne of ore mined. Energy consumption of surface equipment such as hoists and ventilation fans that are directly related to mine operation has been included. In addition to the preceding figures, 3 to 5 kwh per tonne of ore mined are consumed by surface facilities such as mine offices and dry, surface shops and other associated buildings. Any electrical energy used for mineral processing has been excluded from these figures.

The distribution of electrical energy utilization in underground mines is shown in Figure 3.2. The average rate of electricity consumption for all mines is 42 kilowatt-hours per tonne of ore mined. This data can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = +1.95$; and $b = -30.4$.

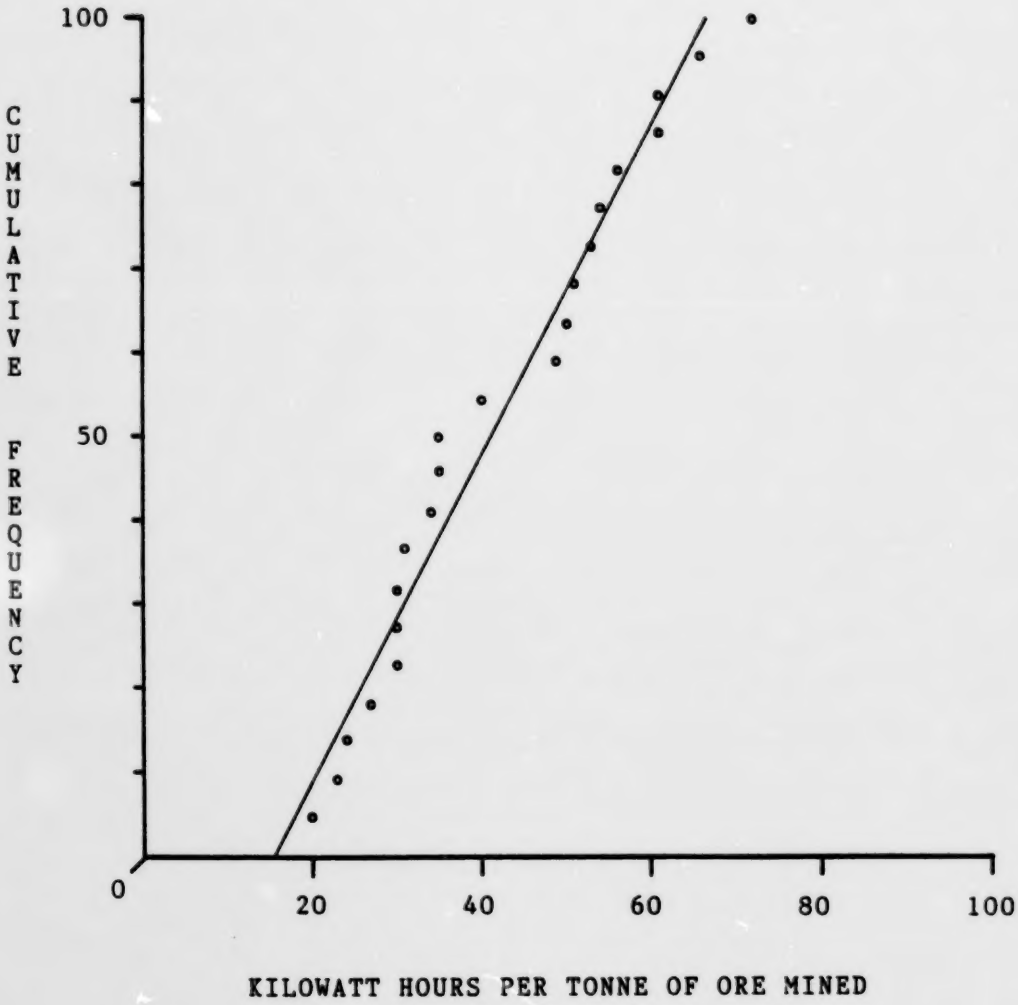
X = electricity consumption in kwh/tonne;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.98.

Figure 3.2

ELECTRICAL ENERGY CONSUMPTION IN UNDERGROUND MINES



ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

On an aggregate scale, it is not possible to establish any correlation between mining method, production rate or mine age in terms of the rate of electricity consumption. While a number of recently constructed mines consumed lower than average amounts of electricity, so did some older mines. While some highly mechanized operations were lower than average in the range, some were higher.

Even for mines with similar mining methods, equipment and production rates, the quantities of electrical energy utilized were significantly different. Even similar mines within the same corporate organization often displayed quite different electricity consumption rates. It is concluded that aggregate comparisons of electricity consumption data are not meaningful, except as a rough measure of electricity utilization.

In order to provide a comparative breakdown to facilitate the evaluation of electricity consumption patterns, data was gathered for the following mining equipment areas:

* Air Compressors
* Ventilation System
* Mine Air Heating (if electric)
* Dewatering System
* Hoisting System
* Ore Handling System
* Other Uses

Air Compressors

The largest single consumer of electrical energy in underground mines is typically the compressed air plant. As shown in Figure 3.3, the average electricity consumption of the mine compressed air plant is 16 kilowatt-hours per tonne of ore mined. This data can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = + 3.73$; and $b = - 6.00$;

X = electricity consumption in kwh/tonne;

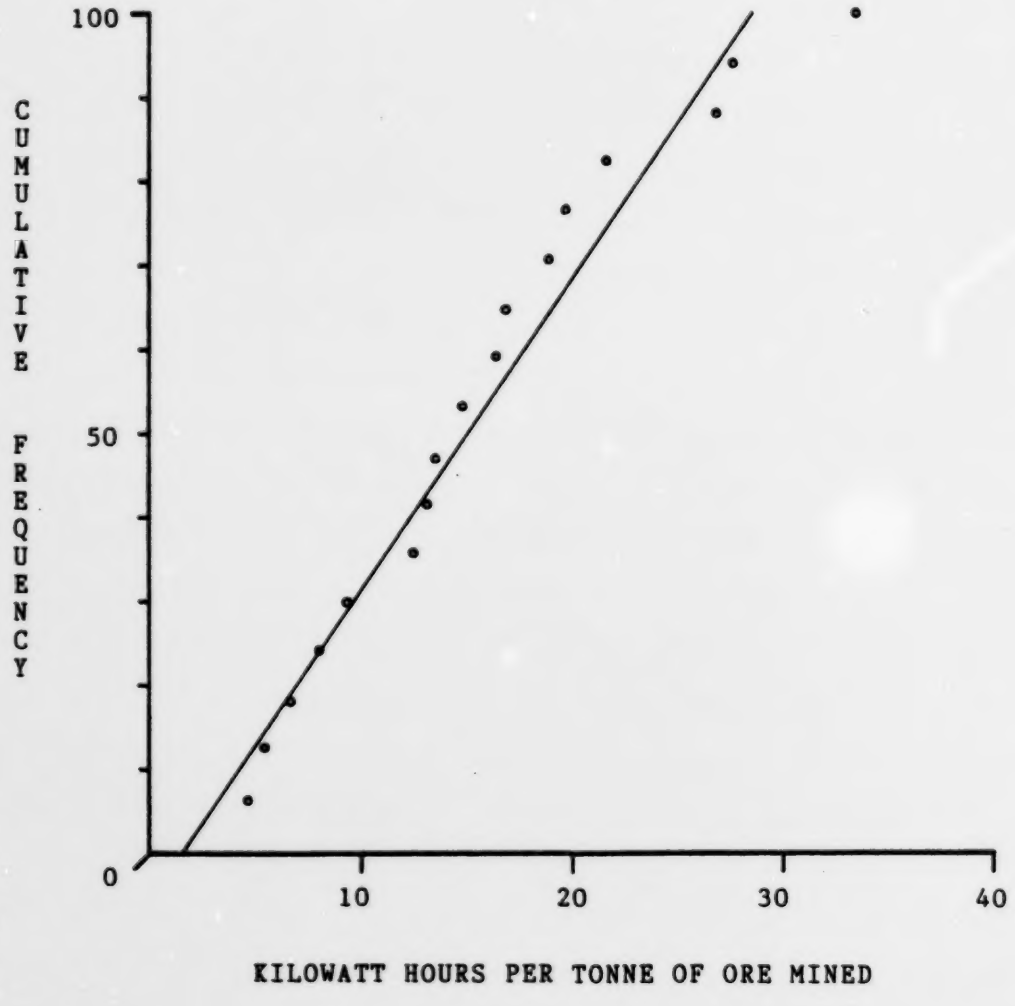
Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.97.

In comparing the air compressor electrical consumption data from individual mines, it is apparent that mines utilizing electric hydraulic drill units use less compressed air than most other mines. These mines report electricity consumption of 5 - 10 kilowatt-hours per tonne of ore for compressor plant operation. It is significant, however, that a few mines utilizing only pneumatically powered rock drills also have similarly low energy consumption figures for compressor plant operation.

Figure 3.3

COMPRESSED AIR PLANT ELECTRICITY CONSUMPTION



ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

Other than the case where electric hydraulic drilling units are used, it is not possible to establish any correlation between mining method, production rate or mine age in terms of compressed air plant electricity consumption, based on the direct electricity consumption. It is concluded that some mines are able to minimize compressor plant operating time through energy conservation measures more so than others.

When the same data is analyzed as a percentage of total mine electricity consumption, however, some correlations do become more evident. As shown in Figure 3.4, mines utilizing electric hydraulic drill units consume only 15 - 20 percent of the total electricity used underground in the compressed air plant.

In contrast, the compressed air plants of other highly mechanized mining operations consume an average of 30 percent of the total mine electricity usage. Data from these mechanized operations can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = +3.62$; and $b = -61.00$;

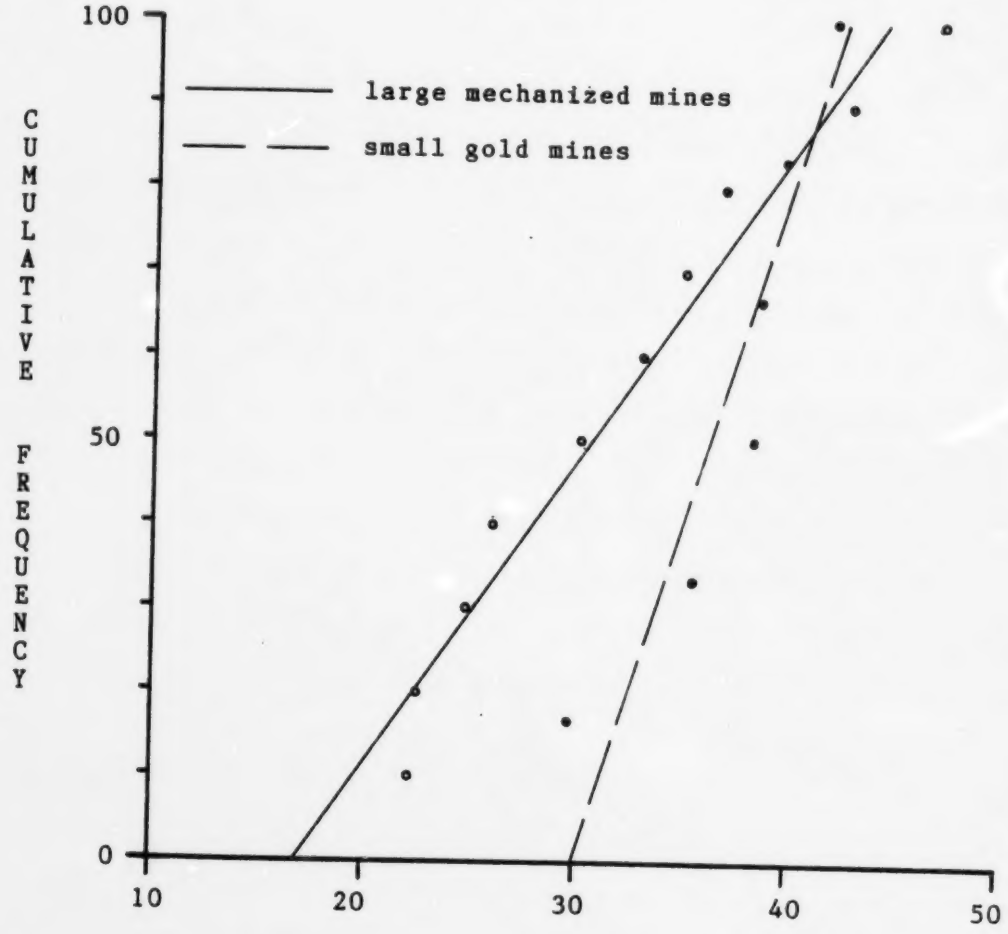
X = percent of total mine electricity consumption;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.97.

Figure 3.4

COMPRESSED AIR PLANT ELECTRICITY RATIO



For gold mines as a separate group, it has been determined that compressed air plants consume an average of 37 percent of the total mine electricity usage. Also as shown on Figure 3.4, data from the gold mines can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = + 7.95$; and $b = - 2.38$;

X = percent of total mine electricity consumption;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.93.

From the preceding information, mine operators can plot data from their own mine sites and can determine the efficiency of their utilization of compressed air relative to the industry as a whole. In addition, within specific industry sectors, it can be determined how their overall energy distribution compares to other mines. Such analysis will highlight possible cost reductions through energy conservation measures and will provide a means of quantifying the savings.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

Ventilation System

The amount of electrical energy required to ventilate underground mines is dependent upon the degree of mechanization involved in the mining machinery in use at different mines. In general, electricity consumption for various types of mines is as follows:

Gold mines, conventional stoping equipment	- 2-3 kwh/tonne
Base metal mines, conventional stoping equipment	- 3-5 kwh/tonne
Base metal mines, mechanized stoping equipment	- 5-8 kwh/tonne
Uranium mines, mechanized stoping equipment	- 9-12 kwh/tonne

Not all mines, however, conform to these classifications. For example, one gold mine using conventional stoping techniques reported electricity consumption of 10 kwh/tonne of ore for mine ventilation. Likewise, a couple of highly mechanized mining operations reported energy consumption data in the 2-3 kwh/tonne range.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

It has been determined that mine ventilation systems consume an average of 5.9 kwh/tonne of ore produced. As shown on Figure 3.5, the available data can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = +8.59$; and $b = +1.86$;

X = electricity consumption in kwh/tonne;

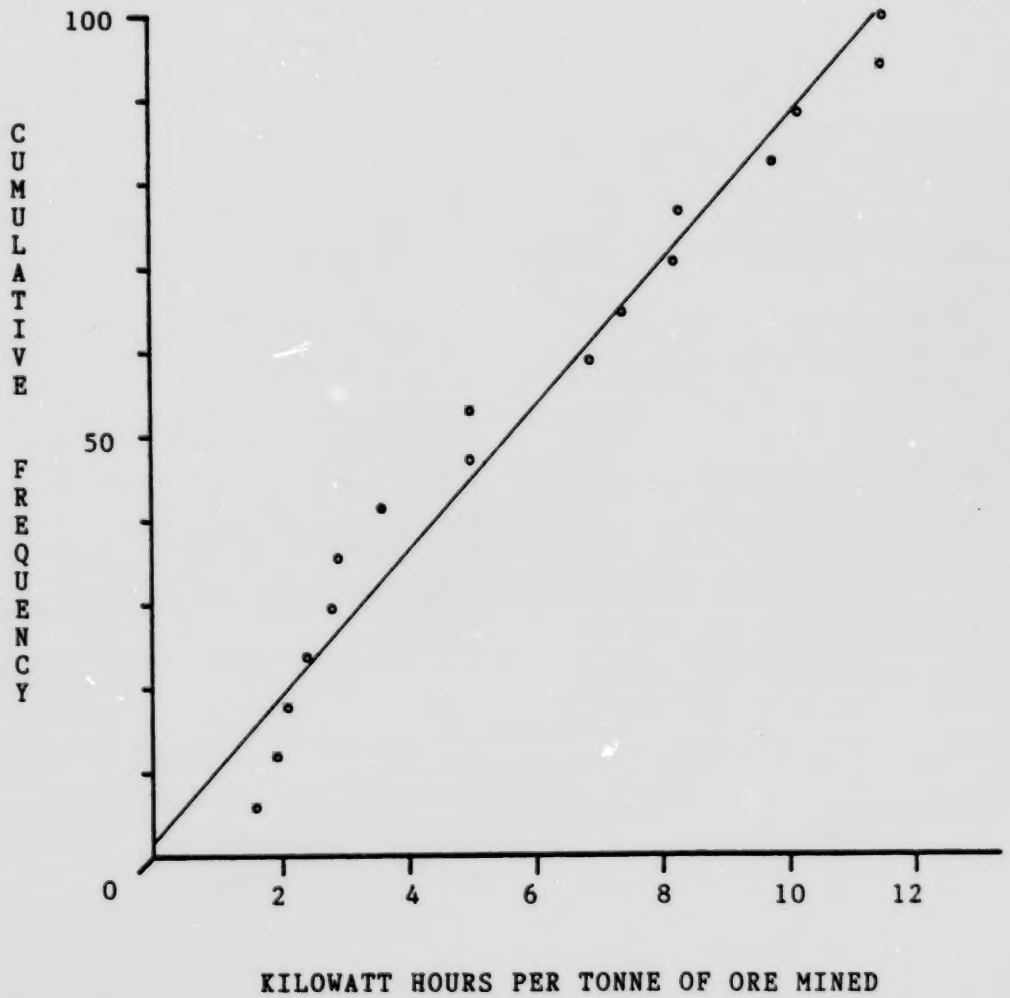
Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.98.

When the same data is examined as a percentage of total underground mine electricity consumption, similar groupings of electricity consumption by mining methods and equipment are evident. Gold mine ventilation systems typically consume between 4-8 percent of the total mine electricity usage, while base metal mines utilizing conventional methods and machinery use between 9-15 percent of total electricity for mine ventilation.

Figure 3.5

VENTILATION SYSTEM ELECTRICITY CONSUMPTION



ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

Several of the larger base metal mines with a high use of mechanized equipment consume between 15-20 percent of their total electrical energy requirements in ventilating underground workings. One mine that uses electric hydraulic drills and other state-of-the-art mining equipment indicated that over 24 percent of total electricity consumption was for mine ventilation.

As shown on Figure 3.6, mine ventilation systems consume an average of 13.8 percent of total underground mine electricity requirements. The available data can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = + 5.03$; and $b = - 16.8$;

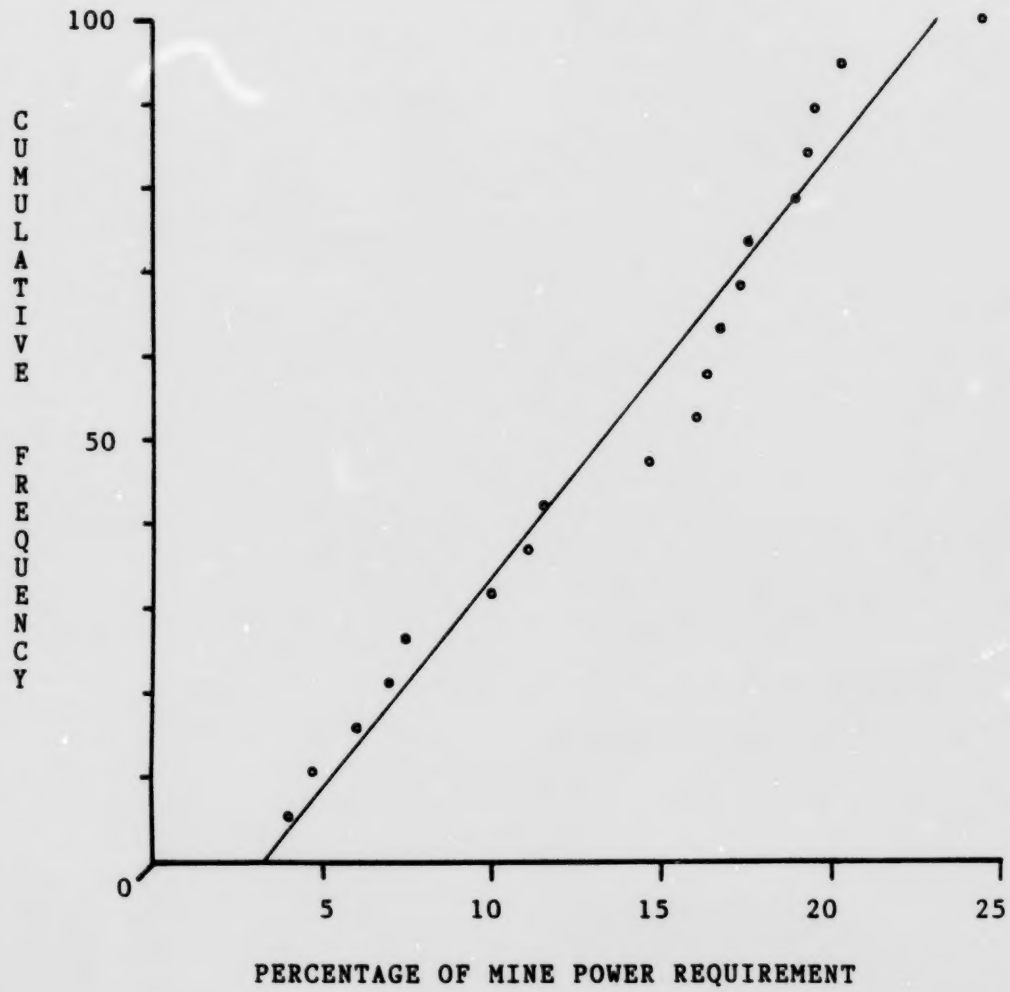
X = percent of total mine electricity consumption;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.98.

Figure 3.6

VENTILATION SYSTEM ELECTRICITY RATIO



Mine Air Heating

An increasing number of mines are relying on electricity for mine air heating. In most cases electricity is used to provide a base quantity of heat, with supplementary propane heat being used on an intermittent basis during very cold periods. With some provincial utilities providing special rates for certain types of energy utilization, some mines find it economical to use electricity as a sole mine air heating source.

At the present time in Manitoba, Ontario and Quebec, electric mine air heating is more economical than propane-fired heaters. Only in areas where natural gas pipelines exist, do mines have a more economical alternative than electric mine air heating.

Due to the nature of the existing installations of electric mine air heaters, it is not possible to provide meaningful statistical information concerning the amount of electricity used by the industry as a whole, nor by an average mine. The use of electric mine air heating is dependent on climate, air volume, degree of regulation involved and other site specific applications. This assessment is best determined on a site specific basis.

Dewatering System

It is not possible to establish any correlation between mining method, production rate, mine depth or mine age in terms of electricity consumption for mine dewatering systems. The average electricity consumption rate for dewatering is 3.9 kilowatt-hours per tonne of ore.

A few mines known to produce substantial quantities of ground water greatly exceed the normal values stated above for typical hard rock mining operations. These mines use from 10-15 kwh/tonne of ore to dewater mine openings. These figures have been separated from the average values due to the site specific nature of the dewatering conditions involved.

As shown on Figure 3.7, the quantity of electricity used for mine dewatering can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = +16.4$; and $b = -10.1$;

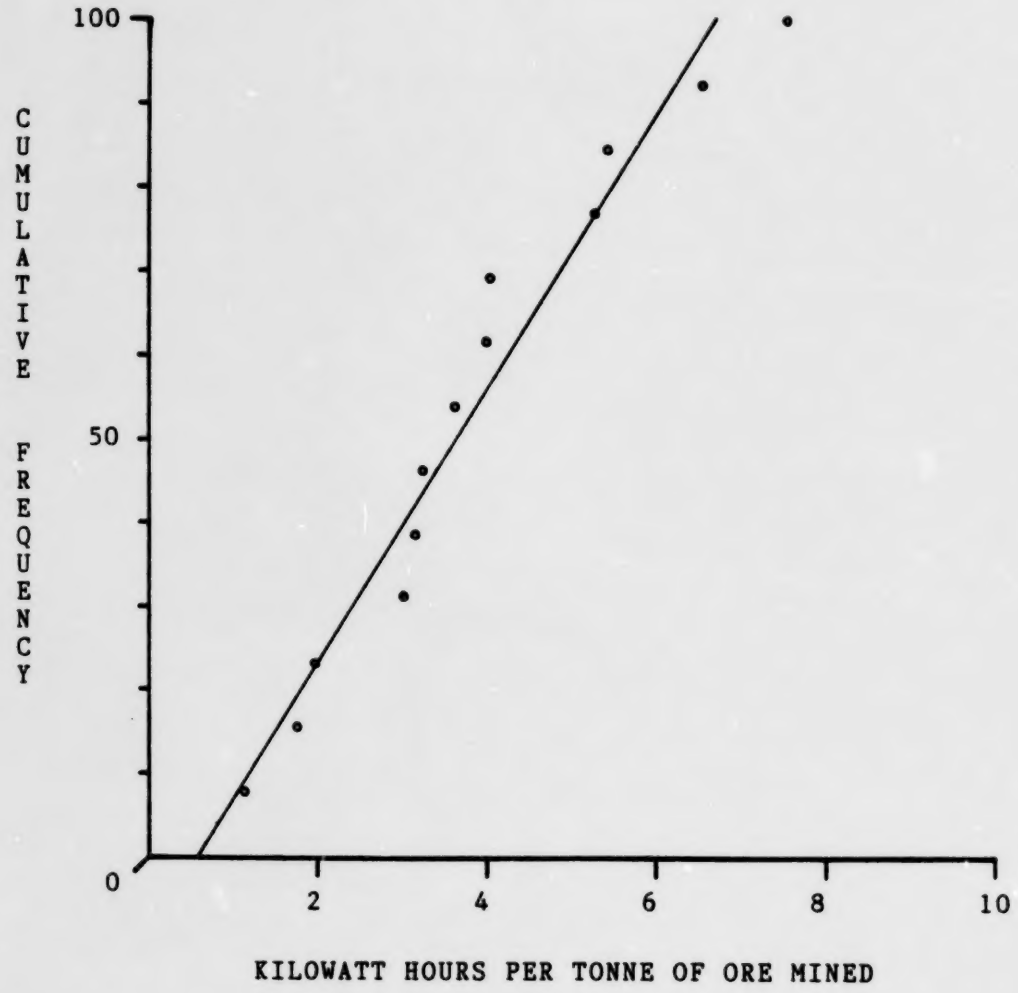
X = electricity consumption in kwh/tonne;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.97.

Figure 3.7

DEWATERING SYSTEM ELECTRICITY CONSUMPTION



ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

On a percentage basis, mine dewatering systems account for approximately 11 percent of the total mine electricity requirements. Some mines with little ground water inflow utilize only 3-7 percent of their total electricity usage on dewatering. Most typical mines fall in the 7-15 percent range.

As shown on Figure 3.8, the percentage of total underground electricity consumption used for mine dewatering can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = + 5.93$; and $b = - 13.8$;

X = percent of total mine electricity consumption;

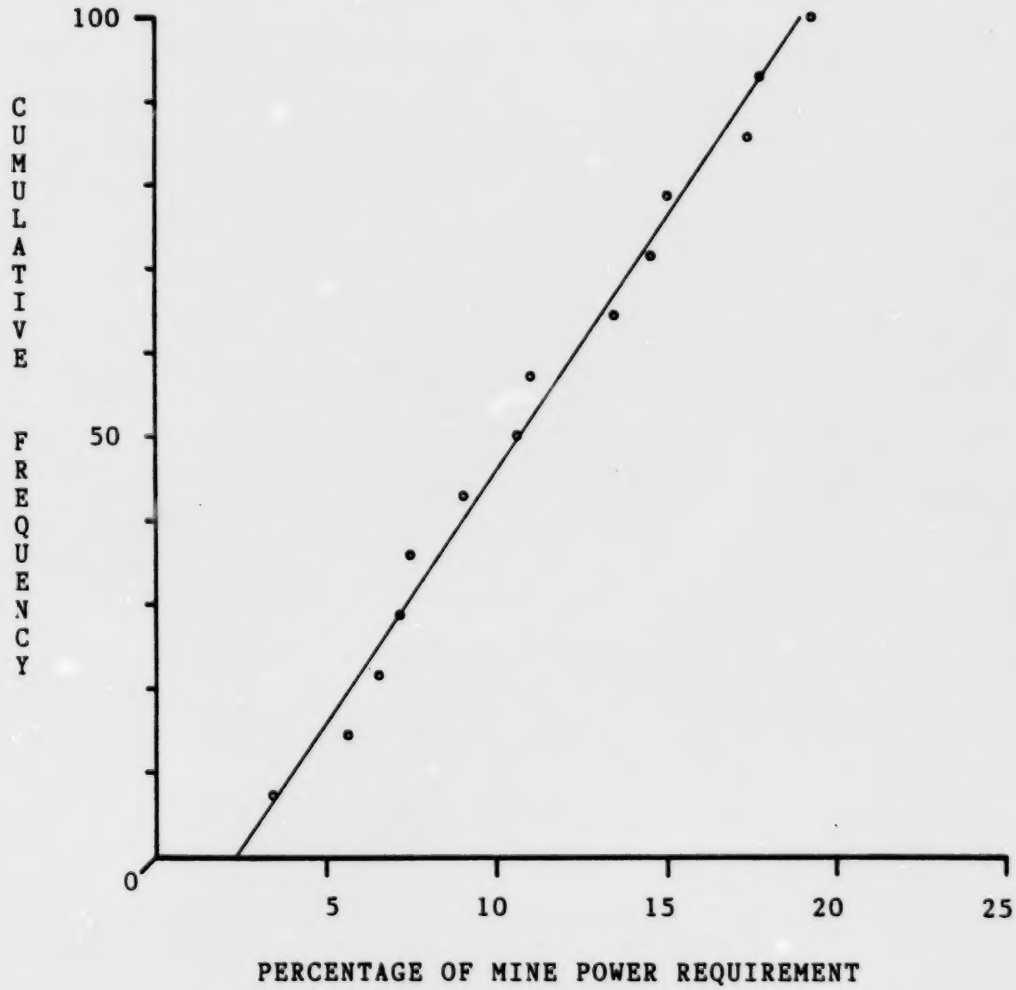
Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.99.

A few mines are notable exceptions and use from 20-30 percent of their total electrical energy requirement on mine dewatering. These mining operations are usually those that have abnormally high quantities of water inflow. The data pertaining to these operations has been excluded from the information shown on Figure 3.8.

Figure 3.8

DEWATERING SYSTEM ELECTRICITY RATIO



Hoisting System

The electrical energy required to operate mine hoists is dependent primarily on hoisting distance or mine depth. In addition, a number of other factors are also important. Some mines operate two or more hoists to service mining operations. Other mines derive a large proportion of production from bottom levels. Some mines have excess hoisting capacity, while others are required to hoist three shifts per day and seven days per week in order to provide mill feed.

As shown on Figure 3.9, the average mine electrical consumption for hoisting is 6 kilowatt-hours per tonne. The range of values indicates lower electrical consumption for mines with limited ore hoisting requirements that rely on other means of ore removal from the mine. Those mines with higher values depend entirely on skip hoisting for ore removal.

The range of electricity consumption values for mine hoisting can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = +13.1$; and $b = -22.1$;

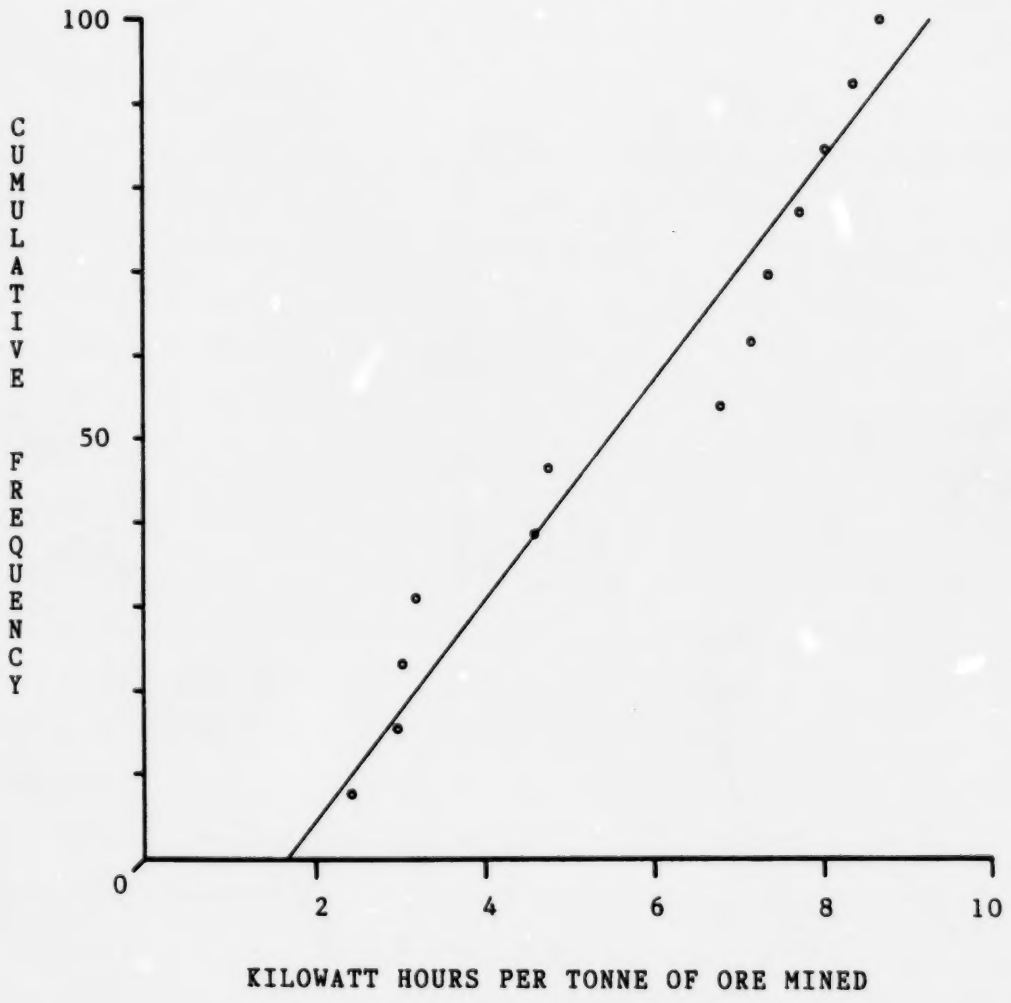
X = electricity consumption in kwh/tonne;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.97.

Figure 3.9

HOISTING SYSTEM ELECTRICITY CONSUMPTION



In addition to the more typical mines on which Figure 3.9 is based, there are a few mines that consume from 10-15 kwh/tonne of ore produced through hoisting operations. Data from these mines has not been included in Figure 3.9 due to the site specific nature of their hoisting operations. These mines operate at much greater depth than normally found in Canada, or use small skips and require a great deal of skipping time to maintain production requirements.

On a percentage basis compared with total underground electricity consumption, hoisting operations require an average of 20 percent of total mine requirements. As shown on Figure 3.10, a wide range of values apply to different mining situations. Both highly-mechanized operations and deep gold mines dominate the above-average group. Other highly-mechanized operations and conventionally equipped base metal operations dominate the below-average group. The range of percentage values of total mine electricity requirements consumed by mine hoisting can be expressed as a linear equation of the form:

$$Y = aX + b$$

where: $a = +3.56$; and $b = -18.2$;

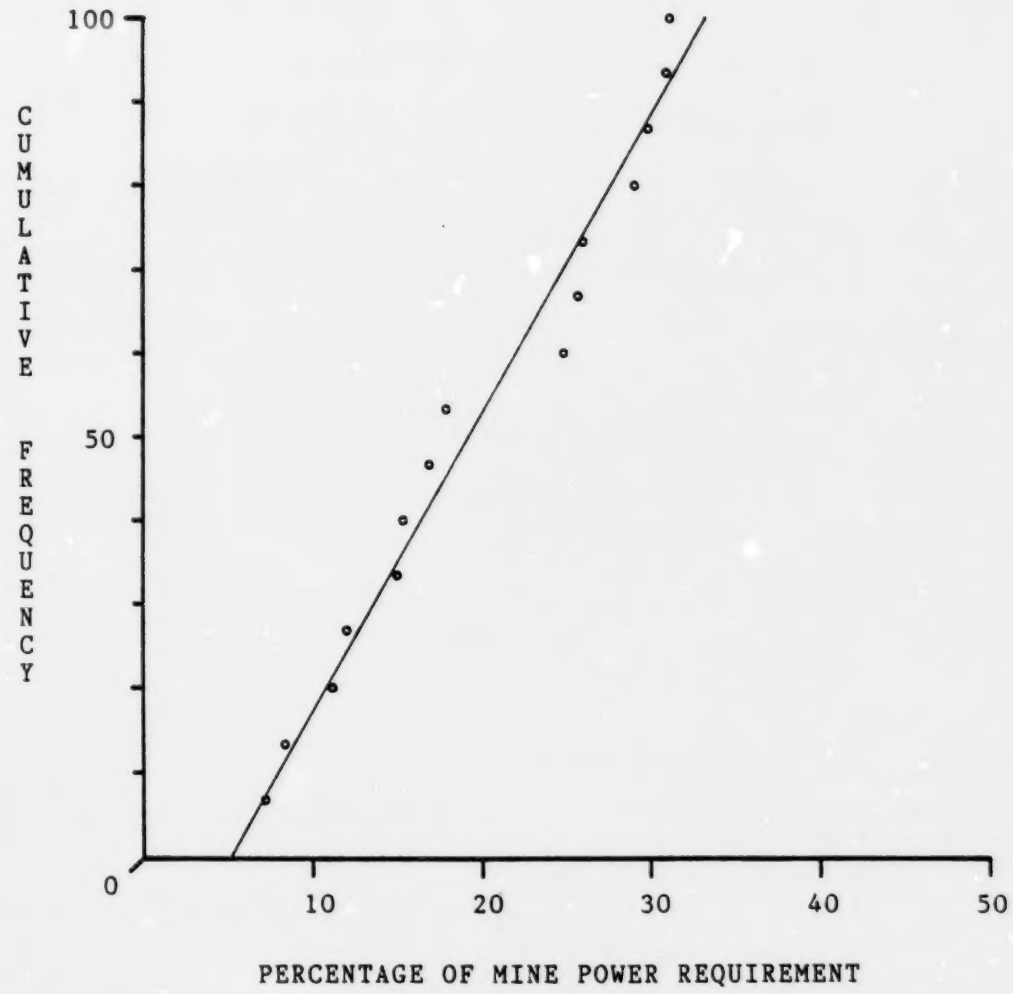
X = percent of total mine electricity consumption;

Y = cumulative frequency (0-100%).

The correlation coefficient for the charted data is +0.97.

Figure 3.10

HOISTING SYSTEM ELECTRICITY RATIO



Ore Handling System

Most mines reported ore handling system electricity consumption of 2-5 kilowatt-hours per tonne of ore produced. These values included the use of intermediate transfer conveyors and locomotive haulage where applicable. Mines within this range of values were found to rely on skip hoisting for ore removal from the mine.

A few selected mines rely exclusively on conveyors for moving ore to surface or feature major conveyor networks for underground ore transfer. These mines reported much higher values of electricity consumption in their ore handling systems. Actual values of electricity consumption depended on the conveyor lengths and slopes involved, but ranged as high as 20-25 kilowatt-hours per tonne of ore produced.

Other Uses

In carrying out the survey of electricity consumption in underground mines, it was recognized that all uses of electricity within underground mines cannot readily be classified into a few discrete groups. In addition, it was expected that most mines would not have uniform classifications for allocating electric power consumption.

For these reasons, mines were able to list as 'other uses' any miscellaneous requirements for electric power. This enabled mines to report their total electricity consumption within a classification framework relevant to the intentions of this project.

The values reported for 'other uses' were typically less than 10 percent of overall power requirements and usually represented load centres in production areas where sump pumps and auxiliary fans were located. In some mines, this classification was also used for load centres feeding electric hydraulic drills, booster compressors and electric LHD units.

3.3 NON-ELECTRICAL ENERGY UTILIZATION

Mine Air Heating

Most underground mine operations in Canada require some form of mine air heating during the winter months in order to prevent both freezing of underground services and accumulating of ice in the mine workings. Most mines rely on direct-fired propane burners as a heat source, although electric heat is rapidly gaining a wider acceptance in many locations. Mines with access to natural gas pipelines find that direct-fired natural gas provides the most economical form of heat for mine ventilating air.

On an annual basis, most mines consume between 5-10 kilowatt--hours of heat equivalent per tonne of ore produced. For these mines, the heating of ventilation air represents the equivalent of 20-25 percent of the amount of electrical energy used at the mine.

Some others, notably uranium mines, as well as those in northern climates, consume between 20-25 kilowatt-hours of heat equivalent per tonne of ore produced. In these cases, mine air heating can require 40-60 percent as much energy as the total mine electricity requirement.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

In reviewing the available data on mine air heating requirements, it is apparent that some mines have better control over ventilation air heating than do others. A few large highly mechanized operations with significant ventilation air requirements still managed to expend relatively little heating energy on mine air heating.

This is contrasted with the data from other medium sized mines that reported significantly above average heating requirements. In other cases, some of the far northern mines reported only average mine air heating consumption figures.

The principal reason for these apparent discrepancies is the degree of control exercised over the use of mine air heating equipment. Those mines with lower heat-per-tonne-of-ore requirements usually had energy conservation programs in effect. These programs resulted in heaters being shutdown or operated at reduced volumes between shifts and on weekends.

In the 1970's most mines adopted direct-fired propane heating systems for ventilation air in order to obtain more efficient utilization of the heat produced. In addition, direct labour savings were also achieved in comparison to the operation of boilers associated with indirect-fired steam heating systems.

With the improvements in control technology over the past few years, the use of electrical heaters provides a more reliable heating source than propane-fired systems. Although the propane systems are efficient to operate, they are difficult to regulate over wide ranges of temperature and are not well suited to changing air volumes. Electrical heaters offer 100 percent efficiency and are well suited to variable heat outputs in response to changes in ventilating air volumes and provide infinitely variable amounts of heat on demand.

The potential for energy savings through conservation of heat utilization is a major advantage of electrically heated systems. When combined with the use of suitable control devices, electric heaters can provide only the minimum heat required by the mine ventilation system. In addition, as demonstrated by the unit costs shown on Table 3.2, electric mine air heating is less expensive than heating with propane.

Table 3.2 - MINE AIR HEATING COSTS

Energy Source	Cost per kwh
Electricity	3.1 ¢
Propane	4.2 ¢
Natural Gas	1.8 ¢

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

Diesel-Powered Equipment

Most underground mines utilize some form of diesel-powered equipment for mine development or ore handling. Many mines are totally dependent upon diesel engines to move drill jumbos, LHD's and trucks throughout various areas of the mine. When the amount of diesel fuel consumed by underground equipment is expressed as equivalent electrical energy, the average energy utilization is found to be 6 kilowatt-hours per tonne of ore produced.

Those mines that are highly mechanized use from 6-10 kilowatt--hours per tonne, while others that rely only partially on diesel equipment use from 0-5 kilowatt-hours of equivalent electrical energy per tonne. In equivalent energy terms this represents from 5-10 percent of the electrical energy used by most mining operations.

Expressed in more conventional units, a highly mechanized mining operation will consume approximately 0.7 litres of diesel fuel per tonne of ore produced. Of this total fuel consumption, 60 percent is used by ore handling equipment such as LHD's and trucks. A further 18 percent is used by drill jumbos and LHD's on development work, while service vehicles and ancillary equipment consume the remaining 22 percent.

4.0 POTENTIAL DEVELOPMENTS

4.1 CONVENTIONAL APPLICATIONS

The list of conventional applications of electricity includes most of the operating and service equipment in underground mining operations. Each of the major equipment items is reviewed below to provide an overview of the past developments, as well as the current state of the art as practiced in underground mines across Canada. In addition, areas with potential for future development related to the further utilization of electrical energy are discussed based on input from mine operators at a large number of Canadian mines.

4.1.1 Mine Hoists

Mine hoists are one of the most visible electrically-powered machines at underground mines. Hoisting power requirements are substantial during the starting and accelerating phases of the hoisting cycle due to the high torque developed during those parts of the cycle. The selection of hoist motor size is determined by the hoisting depth and size of the payload, as well as the hoisting speed and the overall duration of the hoisting cycle. It is important for the hoist motor to be sized to accommodate the heat generated during the starting and accelerating portions of the hoisting cycle.

Many of the older hoists still in service in Canadian mines use wound rotor AC drive motors with mechanically-operated electrical contactors. These units, when in good working order are a viable alternative to newer types of motors, and are advantageous in situations with limited power availability.

Most modern hoists feature DC drive motors which provide a more efficient variable speed drive than wound rotor motors. DC drives are now powered using SCR thyristor controls to replace the older Ward-Leonard synchronous DC generators. New SCR thyristor controls cost approximately two-thirds that of a new M-G set, with used M-G sets in good condition costing about one-third that of a new unit.

DC motors less than 1000 kW in capacity, such as used on a service hoist, typically are connected to the drum shaft through mechanical gearing. Larger motors, such as used on a production hoist, are more frequently custom designed, slow speed DC motors revolving at hoist drum RPM. The cost of these custom designed, shaft-mounted motors is normally less than the cost of a separate foot-mounted motor with mechanical gearing.

Newer applications in hoist motors include the use of cyclo-converter AC drives, although there are none existing in Canada. Also, the use of digital controls to replace the mechanically driven lilly controllers has taken place in other countries, but has not yet been applied to Canadian hoists.

The complete automation of existing hoisting operations is technically feasible for all hoist motor types with the exception of wound rotor motors. However, at a cost of $800 per kW of motor capacity, most mines are presently unable to justify the capital expense of replacing existing DC motor controls to accommodate solid state automatic control equipment.

The potential developments in this area include energy savings made possible through the use of power factor correction, peak shaving and the application of automatic hoist controls to reduce power consumption per hoisting cycle. Unfortunately, these potential cost savings are not readily available to most operating mines due to the lack of technical skills to implement such cost saving measures.

4.1.2 Underground Ventilation Fans

Prior to the introduction of mobile diesel-powered mining equipment, most mines relied on the distribution of fan-induced air flow provided by surface fans, with limited use of underground booster fans. The design of mine openings and structures was such that air was directed through active mine workings. The use of compressed air-driven auxiliary fans was commonplace, as electrical energy was frequently not available in mine development headings. Since mining equipment was also pneumatically-powered, measurable air flows resulted from the use of mining machinery.

The use of electrically powered auxiliary ventilation fans now represents a substantial energy load at most mines using diesel equipment. Many underground working places require dedicated ventilation fans in order to provide sufficient fresh air to achieve effective dilution and removal of diesel fumes.

Ventilating air volume and fan motor size depend on the working diesel requirements, but air volumes of 10-20 cubic metres per second and fan motor sizes of 20-40 kW are typical requirements of many applications. A non-uranium mine will use approximately 10 auxiliary underground fans per 1000 tonnes of daily production capacity, with an average power draw of 25 kW per fan.

Most auxiliary fans are wired only for local start/stop operation, and are not remotely monitored or controlled. Fans frequently run continuously, without shutdown, during working and non-working shifts, as well as on weekends. This is a result of widely-scattered working places, making it impractical to have fans manually started on a demand basis. Due to this practice, the utilization of auxiliary ventilation energy is inefficient, in that fans often operate during times when there is no operating requirement.

One mine projected energy savings of $1,000 per year per fan, if fans could be shut off between shifts after blasting smoke has been exhausted from the mine. This potential energy savings would range from $10,000 per year for a 1000 tpd operation, to $100,000 per year for a 10,000 tpd mine. Most mines have not as yet taken advantage of the savings that could be achieved through the more efficient control of auxiliary ventilation fans.

Typical auxiliary fans are driven by direct-connected in-line 1770 RPM induction motors that provide a constant fan speed. The variable pitch fan blade systems used in other industrial applications have not found wide acceptance in the mining industry due to the low fan pressure capabilities and additional capital costs associated with these fans.

Any requirements for changes in air volume are made by manually resetting the individual fan blades. As this is a difficult task to accomplish in the field, most fan blade settings are not changed as the auxiliary fans are moved from job to job. Similarly, blade settings are not changed as additional length (i.e. additional resistance) is added to the ventilation circuit or ducting.

In order to satisfy the worst case conditions that a fan may be required to meet, most fan blades are set at the steepest pitch possible without exceeding the fan motor capacity. This practice compounds the inefficiency of most auxiliary fan installations when these units deliver the maximum air volume irregardless of the actual site specific requirement.

Variable speed drive units are now available to replace conventional motor starters in order to permit 'soft' starting of fan motors and to allow for infinitely variable fan speeds, within the design limitations of the fan motor and blade characteristics. The price of these variable speed drive units is approximately $200 per kW of fan motor capacity for primary voltage control type motor starters.

Neglecting any savings due to the increased life of ventilation ducting achieved as a result of using reduced voltage starting, a typical 25 kW fan would require an energy cost savings of $3,250 per year to justify using a variable speed drive. This savings assumes a 15 percent return on investment with payback of initial capital within two years.

For mines with electricity supplied by a provincial power utility, a savings of 105,000 kWh per year would be necessary to justify the installation of variable speed drives, assuming a power cost of $0.031 per kWh. For mines relying on diesel generated electricity, a savings of only 15,500 kWh would be necessary, assuming a power cost of $0.21 per kWh.

In order to achieve this level of savings on a 25 kW fan installation, a 50 percent reduction in operating time would be necessary based on utility rates, compared with savings of less than 10 percent based on diesel-generated power. The potential exists to improve the efficiency of underground ventilation fans through the introduction of suitable control and monitoring equipment. The total of direct and indirect savings that can result from the use of these systems could far exceed the rigorous criteria outlined above.

4.1.3 Dewatering Pumps

Mine dewatering installations typically reflect the changing conditions and requirements for dewatering as mines have expanded both horizontally and vertically. Older pumping installations used a number of smaller pumps with low voltage (575 volt) motors for stage pumping from the shaft bottom to surface.

With the increasing availability of higher distribution voltages underground over the years, the use of larger capacity, high pressure, single-lift pumps with 2300 V or 4160 V motors. Pump controls were usually set independently for each pump by the use of float switches located in the sump. The coordination of pump starting sequences was normally not possible unless pumps were located in the same station.

Conventional mining techniques using rail-mounted equipment normally progressed on an upgrade away from a shaft station, thus enabling water to drain from mine workings without requiring the use of pumps. The wide acceptance of mobile trackless mining machinery has made it possible to drive openings at substantial decline gradients.

The use of air-operated pumps was found to be restricted to limited flows of water and for short lifts. The resulting deployment of electric pumps for the dewatering of decline development headings, as well as the need for electric ventilation fans, have been the primary reason for the extension of power cables throughout mine workings.

The determination of sump capacity is also being given more serious consideration as the cost of energy increases. Adequately sized sumps permit the proper balancing of pump running times and control of starting frequency in order to achieve system economies not possible with earlier generations of pump controls.

One major dewatering problem still not resolved at most mines is the removal of slimes from dewatering sumps. Some mines use sludge handling units such as Zimpro or Mars pumps to remove sludge from underground settling sumps. Other mines have incorporated conical sump designs so that mobile equipment can be fitted with tanks to withdraw the sludge from the bottom of the settling cones and tram it directly to surface. Many mines, however, still use manual labour and small rail-mounted cars to clean slimes from underground dewatering sumps.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

Present trends in mine dewatering include the use of more sophisticated materials for pump construction and improved pump design for reduced maintenance and higher efficiency. Larger mines are using system-wide sequencing controls to monitor all major sumps and pump status. In this way, the peak pumping power requirements can be minimized by reducing the concurrent operation of multiple pumping units.

4.1.4 Slusher Hoists

The use of double and triple drum slusher hoists will be an integral requirement of many mining systems for years to come. Some of the larger underground mines in Canada are still dependent on the use of slushers for the movement of a significant proportion of their daily ore production.

Despite the popularity of mobile trackless LHD equipment, several larger base metal mines do not find it economical to convert some areas of their existing operations to accommodate the use of trackless equipment. In these situations, the costs associated with redeveloping some ore blocks are not justified by the tonnages and ore grade remaining.

Many existing gold mines have also not found a suitable alternative to the use of slushers in the mining of narrow vein ore zones. Although most gold mines now use electrically-powered slushers, some mines still rely on compressed air for slusher operation. The gold operations using electric slushers, as well as the larger base metal mines, report that electric units are faster and have superior operating characteristics compared with pneumatically-powered units. An important additional benefit is that the slusher operator is also provided with ample lighting to improve workplace visibility.

Slushers are not usually considered to be a modern piece of mining apparatus as the production rate of most units is low compared to LHD equipment. However, the initial capital cost is low, the operating costs are minimal and the intervals between maintenance requirements are long. These features remain attractive to many mines which operate on limited financial budgets.

One large operating mine, planning for a major expansion, seriously evaluated converting an existing mobile operation back to using slushers as a primary ore handling unit. Although the decision was subsequently made to remain with trackless mining methods, the economics of using a slusher-based mining method were reported to be very attractive by comparison.

Another major underground mine is currently operating a prototype slusher controlled by a computer. Trial results are very encouraging, with the unit having operated hours at a time without manual intervention. Significant increases in productivity are anticipated from slushers once these computer controlled units become more widely used. A manufacturer of mining equipment has expressed interest in developing an electric hydraulic drive for slushers that would provide superior operating characteristics as compared with existing units.

4.1.5 Mine Locomotives

Many Canadian mines rely on underground locomotives as a means of transporting men and materials, as well as ore and waste production. The low capital cost of battery locomotives has enables their use to become widespread throughout the industry. Trolley locomotives are used in specific situations where the ore haulage requirements are sufficient to justify the additional capital cost.

Mine locomotives are of robust construction and have extremely long lifespans. A number of mines are using trolley haulage systems that were installed in the 1920's and 1930's. Many gold mines use the Little Mancha Trammer, a 1.5 ton locomotive suitable for hauling two or three 44 cubic feet capacity mine cars.

The use of diesel-powered locomotives has been applied by several mines for specific haulage functions. In situations where load requirements exceed the capacity of battery locomotives, but where trolley systems are not economically viable, diesel locomotives have been used. The use of diesels, however, is unlikely to become widespread because of the relatively high maintenance requirements for diesel units and the necessity of providing adequate quantities of ventilating air.

A few mines have used various forms of remote control systems on battery and trolley locomotives to enable chute pullers to shunt cars at loading and discharge points. More mines are now investigating the possibility of using remote control locomotives as a means of eliminating one of the two men now required on many underground haulage systems.

Although most mine operators are familiar with European examples of automated train operations, there are no fully automated mine haulage systems operating in Canada. Generally, mine operators do not perceive that train automation would be applicable to their existing mining operations.

Recent Canadian developments in mine locomotive technology include the retrofitting of old battery locomotives with SCR control units to eliminate the maintenance-prone contactor relays supplied as original equipment. Some Canadian suppliers of locomotive repair components are now beginning to investigate the development of an advanced-design of radio remote control systems for both battery and trolley locomotives. The proposed systems would incorporate significant improvements in braking capability and would establish an intermediate step to full automation of both small and large mine locomotives.

Potential developments include the adaptation of new battery technology being developed for uses in other industries. These developments are aimed at providing improved ratios of energy to weight and volume compared with the lead-acid batteries presently in use.

Examples of new battery technology include the nickel-zinc battery developed by NASA and an experimental alkaline iron-nickel battery developed by Westinghouse. These newer batteries will operate for longer time intervals and will require less time for recharging. In addition, increases in battery output power will make it possible to haul heavier loads than is the case with existing batteries.

4.1.6 Rockbreakers

The use of mobile and stationary rockbreaker units to break oversized chunks of ore and waste is increasing in Canadian mines. Early designs used an electrically-driven hydraulics system for boom movements, in conjunction with a pneumatically--operated hammer. This type of unit is typical of many current installations in Canadian mines.

The mining industry intends to adopt a wider utilization of rockbreakers, rather than rely on secondary blasting for breaking oversized rocks. The safety-related advantages of avoiding the use of explosives and the resulting interference with other mine activities, is the principle advantage of using these units. In some mines, the use of rockbreakers has eliminated the requirement for underground jaw crushers. A capital cost savings of 50 percent is achieved when comparing the installed cost of a rockbreaker system to a crushing system.

Newer rockbreakers incorporate hydraulic hammers to provide additional impact energy while using a hammer of smaller physical dimensions. These units are fully electrically powered, as compressed air is not required for machine operation. The increased energy efficiency, while of interest, is a secondary consideration for most operators when compared with reductions in capital costs and increased productivity levels.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

The size reduction of large pieces of ore by rockbreakers is economically efficient as shown on Table 4.1. The unit operating cost is less and the installation is only a fraction of the high costs associated with underground crusher stations. Furthermore, rockbreakers used upstream of crushers may reduce crushing costs by 30 percent by eliminating hang-ups in orepasses. These units are able to pre-size the muck being fed to crushers, increasing the proportion of undersized material and resulting in reduced crusher demand.

Table 4.1 - **ROCKBREAKER AND CRUSHER COST COMPARISON**

	Rockbreaker	Crusher
Tonnes Per Day Capacity	2,000	3,000
Capital Cost		
Equipment Purchase	$ 75,000	$ 250,000
Underground installation	$ 45,000	$ 950,000
Operating Cost Per Tonne		
Labour	$ 0.30	$ 0.20
Wear Parts	$ 0.25	$ 0.40
Total Operating Cost Per Tonne	$ 0.55	$ 0.60

4.1.7 Conveyors

Underground conveyors are used to convey crushed ore from a crusher station to underground storage silos or to loading pocket bins. Some fully and semi-automated loading pocket installations also use short conveyors to feed ore into shaft-side measuring boxes.

One large underground operation uses a network of conveyors to collect grizzly-sized uncrushed ore from production areas for transport to central crushing and hoisting stations. A few additional mines use conveyors for elevating ore production from lower levels either to surface, or to internal haulage horizons. These operations tend to have ore zone geometries that are better suited to conveyors than to conventional vertical shaft hoisting, or to horizontal truck and train systems.

Canadian underground mining operations use many of the recent advances in conveyor technology, including variable speed drives, cable-driven belts and automated conveyor control componentry. Most conveyor systems are used in a semi-automatic mode with sequential interlocks for startup and safety stops.

Mine operators view conveyors as having potential for much wider application in underground operations as a means of minimizing manpower requirements associated with ore and waste handling systems. Conveyor control systems are rapidly developing to the point where fully automated conveyor systems are thought to be applicable to mining activities.

In addition, a number of mine operators expressed the intention to use conveyors as a primary means of moving ore from stopes and stope drawpoints to orepasses. It has been proposed by some mines that primary blast-induced fragmentation can be achieved economically such that muck can be directly loaded onto conveyor belts.

Other mines expressed the desire to develop suitable portable hard-rock crushing units to reduce the blasted ore to conveyable size. A number of portable crushers are now being used in Canadian surface mining operations and one company is active in developing suitable equipment for underground applications.

It was the general concensus of many hard-rock mine operators that potash and coal mining systems are organized in such a way as to minimize manpower requirements through the effective use of conveyors. It was repeatedly mentioned that conveyor systems represented the most likely means of replacing the present LHD/truck combinations currently being used in many base metal and gold mines with bulk mining methods.

The pending introduction of hard-rock tunnelling machines to the Canadian mining industry for the rapid development and installation of conveyor galleries could significantly alter the present economics of mine conveying systems. In addition, the use of steeply inclined conveyors represents another possible opportunity for some specific mining applications.

4.1.8 Crushers

As previously mentioned, a trend has been noticed whereby rockbreaker units are increasingly being used to eliminate the requirements for underground crushers in mines up to 2000 tpd capacity. Larger mines will continue to utilize stationary crushers, with the tendency being to use larger units capable of handling larger chunk sizes.

In many existing operations, the major bottleneck in ore handling systems has been the feed chute leading into the crusher, often causing hangups upstream from the crushing chamber. More frequently, the bottleneck is now being built into the orepass dump by using a fixed grizzly or other constricting device.

With the use of LHD machines in the 8 cubic metre bucket size and larger, many existing mine crushing systems are not designed to handle the massive chunks of ore that these machines are capable of transporting to the orepass. Some mines are of the opinion that ore handling systems, including crushers, should be designed to handle large chunks of ore without bottlenecking. Other mines are of the opinion that improved primary blast fragmentation is the most economical approach to this problem of oversized muck.

The use of portable crushing units, maintained in close proximity to the active muck producing stopes, is expected to be a cost effective approach to ore size reduction. By reducing haulage distances to a minimum, the number of LHD units can be drastically reduced and truck haulage can be eliminated, thus offsetting the capital costs of such crushing systems.

The principal savings from this approach is expected to result from significantly reduced manpower requirements, with corresponding improvements in productivity and mining costs. It has been stated that the closer to the muck pile that size reduction can be achieved, then the greater will be the cost savings downstream through the subsequent stages of ore handling.

4.1.9 Alimak Raise Climbers

The Canadian mining industry has approximately 100 Alimak raise climbers operating within operating mines and by mining contractors on mining projects. Approximately 20 of these are electrically-driven with the remaining units being pneumatically powered. Although diesel-powered units are used in Europe, they have not been used at Canadian mines.

Most raises less than 150-200 metres in length are driven by pneumatically-powered equipment. For raises in excess of these lengths, the electric machines are preferred as the full climbing speeds are sustained over the full raise length.

The use of Alimak raise climbers will be continued within the industry, as this type of equipment provides a cost effective means of raise driving in most circumstances when compared with raise boring. The cost comparison data presented in Table 4.2 illustrates the differences between the various cost elements for4 both Alimak raise driving and raise boring. It is noteworthy that the drill-and-blast method is less expensive despite a higher manpower requirement and significantly higher costs for energy (explosives) consumption.

Table 4.2 - **ALIMAK VS. RAISEBORING COST COMPARISON**

Item	Raise No.1		Raise No.2	
	Alimak Raise	Raise Boring	Alimak Raise	Raise Boring
Length of Raise	250 m	250 m	100 m	100 m
Time to Complete	61 days	28 days	25 days	15 days
Direct Cost Breakdown				
Setup & Teardown	$ 25,000	$ 55,000	$ 20,000	$ 55,000
Raising Labour	$ 73,000	$ 34,000	$ 25,000	$ 18,000
Supplies and Rental	$ 42,000	$125,000	$ 17,000	$ 67,000
Subtotal Direct Cost	$140,000	$214,000	$ 62,000	$140,000
Energy Cost Breakdown				
Explosives	$ 43,000	$ -	$ 17,000	$ -
Compressor Usage	$ 4,000	$ 3,000	$ 1,700	$ 1,000
Electricity Usage	$ -	$ 6,000	$ -	$ 2,500
Subtotal Energy Cost	$ 47,000	$ 9,000	$ 18,700	$ 3,500
Total Raising Cost	$187,000	$223,000	$ 80,000	$143,500
Raise Cost Per Metre	$ 748	$ 892	$ 800	$ 1,435
Energy Cost Per Metre	$ 188	$ 36	$ 187	$ 35

4.1.10 Hard Rock Boring Equipment

Canadian mining companies and contractors use approximately 46 raise boring units capable of driving raises from 1.2 metres to 3.0 metres in diameter, over lengths up to 500 metres in a single pass. Raise boring machines are used where the speed of raise development, lack of raiser miners, or other considerations such as raise length justify the cost premium normally associated with the machine excavation of mine raises.

Raise boring machines rely on electrically driven motors and hydraulic pumps to provide the torque and thrust requirements of the machinery used in raise boring. Various types of drive units are offered by the two remaining equipment manufacturers. These drives include AC, DC and hydraulic units, depending on raising requirements and customer preferences.

Computer-based controls for raise boring machines have been available for a number of years, although their use has only recently been accepted by the mining industry. The application of current control technology has been demonstrated to significantly improve raise boring speeds in all ranges of rock hardness.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

The wider acceptance and implementation of fully automated raise drills to permit machine operation between shift changes will further enhance productivity by increasing machine utilization. The use of solid state controls with diagnostic fault finding capability is expected to result in improved machine availability, thereby also contributing to increased daily production rates.

The net effect of these control technology applications will be to reduce the cost advantage in raise driving presently in favor of Alimak raise driving methods. As a result, more electrical energy will be directly substituted to replace energy presently provided by pneumatically-powered rock drills and explosives.

The major manufacturers of tunnel boring equipment are presently involved in developing TBM equipment suited to mining industry requirements. The rock strength threshold of TBM mining is steadily rising as new machine and cutter technology is proven and subsequently extended.

ELECTRICITY UTILIZATION: TRENDS IN UNDERGROUND MINING

In recent years, any improvement in mine development advance rates within the mining industry has usually required an increased heading size to facilitate the entry of larger, more productive equipment. The development of small diameter (2-3 metre) hard rock TBM equipment is currently in the field trial stage.

These units have the potential to provide high rates of advance in a smaller heading size. The resulting overall benefit to mines is expected to be a significant reduction in preproduction mine development schedules. This will accelerate cash flow by placing mines into production more quickly than is currently possible using drill-and-blast methods.

4.1.11 Mine Lighting

Traditionally, underground mine lighting has been installed at major shaft stations, in electrical substations and at mine refuge stations. Elsewhere, in drifts, raises and stopes, the sole source of mine lighting was the personal cap lamp carried by each individual miner.

In many Canadian mines today, there have been few changes in mine lighting practices. Some mines, however, are more progressive in the use of lighting as a preventative measure to improve visibility with the expectation of minimizing the risk of accidents.

As mining methods and equipment changed, and particularly as mobile equipment was introduced, a corresponding improvement in mine illumination was achieved. Pneumatic drill jumbos incorporated compressed air-driven generators to power headlights for lighting development headings.

The use of electrically-powered mobile equipment has made it possible to significantly increase the lighting levels in the vicinity of mobile equipment. The construction of underground service shops, warehouses and parking areas for mobile equipment required the deployment of lights to attain comparable lighting levels to those found in surface buildings.

Some mines have instituted policies of having lights at the top of all open holes, such as ore and waste passes, as a safety measure. Others place spot lighting at strategic intervals along a ramp or drift to enhance mobile equipment or personal lighting levels in specific locations, such as at the junction of development headings.

A few mines deploy lighting in stoping areas as a safety measure where electricity already exists to power slushers or other equipment. The trend to use more mine lighting appears to be most prominent at mines that have demonstrated superior safety records relative to the mining industry as a whole. The increased use of mine lighting will accelerate as mine operators begin to appreciate the significance of, and endeavor to reduce the economic penalties of mine accidents.

4.2 Electric LHD and Truck Units

Electrically powered LHD units were initially developed for use in Canadian gold mines that did not have sufficient ventilation capacity to enable the use of diesel powered equipment. Over the last decade, electric drives have been gradually introduced to larger sized LHD units and have become commonplace in many mines.

Typical applications for electric drive LHD units are within cut-and-fill stopes or on drawpoint mucking where high ambient heat temperatures or lack of adequate ventilation air capacity prohibits the use of diesel powered units. A few mines have used electric LHD machines on mine development and reported no major problems in adopting their use. In these situations, the LHD normally trams to a remuck station where the power cable is also terminated. The LHD dumps directly into haulage trucks or into the remuck station if no trucks are immediately available.

All users of electric drive LHD units report operating cost reductions from 25-50 percent when compared against diesel powered machines. In addition, productivity improvements of 15-20 percent were attributed to the superior operating power characteristics associated with electric drives. The LHD bucket breakout forces are much higher with the electric LHD, thereby contributing to a faster bucket loading cycle.

In addition, the reduction in noise levels and the absence of diesel exhaust emissions contribute to an improved operating environment for machine operators. At the same time, the lack of fueling requirements eliminates a major logistical obstacle associated with diesel powered machines, especially in captive stoping situations. Similarly, the cooler operating temperature of the electric machines prolong the life of the hydraulic fluids, seals and componentry thereby increasing the interval between maintenance requirements.

Despite these readily apparent cost and productivity advantages, few newer mines are using electric drive LHD units. Even in mines that make extensive use of electric hydraulic drill jumbos, the view of many mine operators is that the use of trailing cables would restrict the useful applications for electric LHD machines at their operations.

However, those mines presently using electrically powered machines report no serious impediment due to the use of trailing cables that cannot be easily accommodated. By providing protection at corners to prevent damage to the trailing cable, and by strategically locating the cable anchor point, most LHD applications can be accomplished as easily as with diesel powered machines.

Many mines that are unable to afford or justify the use of specialized service vehicles for moving materials and supplies from place to place within the mine rely on LHD machinery to perform ancillary tasks. Most mine operators realize that this is an inefficient use of their equipment, but are not able to organize their operations differently.

As a result of not wanting to forego the high mobility of diesel powered equipment, these mining operations are reluctant to consider the use of electrically powered LHD equipment. Similarly, mines that draw their daily production requirements from a number of stoping areas believe that electric powered LHD machines lack the necessary mobility to move easily between working places.

However, a few mines have been determined to take full advantage of the electric-powered LHD units and report that lack of mobility is not a major concern or problem in their operation. These mines relegate the majority of their ancillary service requirements to low cost service vehicles that are allowed to stand idle when not in use. These operations tow their electric LHD units from place to place as required to ensure that a high degree of utilization is achieved. They report overall savings in equipment, labour and ventilation requirements.

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The economic equation for justification of electrically powered equipment involves several offsetting alternatives, since electric equipment typically has a higher capital cost in contrast to a lower operating cost. The use of electric drive components increases the cost of mobile equipment by 20-40 percent as compared with comparably sized diesel powered units. Additional costs are also incurred for power distribution systems. However, mine operators report that direct cost savings are realized through improved equipment availability and reduced hourly operating costs.

The cost savings achieved by converting to electrically powered equipment can be significant. For example, in a mine operating at a depth of 900 metres, the typical annual cost of fan operation, air heating, ventilation-related excavations and controls is estimated to be $625 per cubic metre per second of ventilation capacity. Comparable cost savings can be achieved with auxiliary ventilation fans and ducting from reductions in ventilation requirements.

When the use of a large equipment fleet is contemplated, adequate ventilation cannot be provided by simply increasing the number and size of ventilating fans. Usually, the entire ventilation network requires major revisions to make the most efficient use of the available air supply.

Truck haulage is commonly used underground in high tonnage operations with widely scattered workings. In most cases, trucks are usually more efficient than LHD equipment at one way haulage distances exceeding 750 metres.

Trucks usually have large diesel engines that require additional ventilating air volumes. Diesel engines must be provided with 0.06 cubic metres of fresh air per second per kW of diesel engine power. For example, a medium capacity 23.5 tonne capacity truck requires additional ventilation capacity of 8.1 cubic metres per second of fresh air.

The development of trolley systems for trackless vehicles received a great deal of interest in the early 1980's. A few years ago, a major mining company and equipment manufacturers combined forces to develop electrically powered haulage trucks with minimized ventilation requirements.

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Despite encouraging underground field trials with LHD equipment, the additional costs associated with purchase and installation of the trolley rails ($200 per metre), as well as the additional excavation requirements have to date precluded the use of this technology in underground mines. The rationale for attempting the development of the trolley truck was based on a site specific requirement, with the hope that once the technology had become developed, than more users would adopt the use of similar systems.

In the case of the originating mine, the advantage of the trolley truck system would have provided a low cost alternative for mining ore from the bottom levels of the mine with a minimal change in the overall ventilation requirements of the existing mine. In addition, no deepening of the existing shaft or relocation of the existing crushing station would have been required.

As it turned out, the mine ultimately decided to adopt more conventional technologies for moving the ore from the bottom mine levels and decided not to pursue the deployment of the trolley system within the mine. In hindsight, the trolley truck alternative was only one of a number of alternative solutions to a site specific problem.

The passage of time, the transfer of key personnel, the decline in metal prices and a volatile investment climate combined to making the decision to select another alternative solution with fewer technical constraints. A second mine that was also considering use of the trolley truck concept similarly decided against that option for much the same reasons.

In the case of the second company, the requirement was again site specific, and involved the increasing of mine production from areas below the current working levels. The existing ore handling system was operating at full capacity and the use of a trolley truck system was seriously considered as being the optimum means of increasing mine production from the lower production area.

However, with the decline in metal prices, the investment capability of the company became seriously impaired and the trolley truck system concept was dropped. The conclusion drawn by most mine operators is that the use of trolleys on LHD and truck units is not a universally applicable technology. The high fixed cost associated with the trolley track is seen as being the major disadvantage of this type of equipment. Few mine operators saw any possibility of wide application of such systems.

The potential does exist, however, for further developments in the use of electric power for LHD and truck equipment in underground mining. It is the opinion of a number of mine operators that the price of electrically equipped units has the potential to be reduced to less than that of diesel equipped units. This is expected to happen by the replacement of existing componentry using improved hydraulic circuitry and controls, thereby reducing the electric motor size required to perform the same level of work.

In addition, the development of custom built LHD and truck vehicles for specific applications at individual mine sites will provide the opportunity for mine operators and equipment manufacturers to attempt new innovations in component design and application.

4.3 ELECTRIC HYDRAULIC DRILLING

The development of electrically powered, hydraulically operated rock drill jumbos took place in Europe, with the first units being imported to Canada in the early 1970's. The wider acceptance of these units did not take place until the early 1980's with the expansion programs being undertaken in the uranium mines of Elliot Lake.

Both Denison and Rio Algom had relied on the use of pneumatic rock drills for over 20 years and were leaders in the application of drill jumbos and drill carriers of various descriptions. With plans to expand production levels significantly, while at the same time mining in lower reef heights, the use of hydraulic drill jumbos became the obvious alternative.

The hard, abrasive quartzite host rock held pneumatic drill penetration rates below 600 mm per minute and required frequent bit changes. The move to hydraulic drilling enabled penetration rates or 1200 mm per minute to be achieved and the development of button insert drill bits reduced the frequency of bit changes. As a result, the Elliot Lake mines provide the largest concentration of hydraulic rock drills in Canada, and rely on manufacturers from Canada and overseas for the supply of drills and ancillary components.

Other mining camps have been much slower to take advantage of the increased penetration rates offered by hydraulic drill rigs. Many of the smaller mines are not able to accommodate the bulky drill carriers required to move the drills from place to place. Others do not have the electric power available at the working headings to supply the drilling units.

Most mines find it difficult to justify the use of hydraulic drills on economic terms due to the high capital cost of the imported drilling equipment. For mines with restricted access to and from working places, the utilization of hydraulic drilling equipment is restricted by the lack of available working faces.

The apparent advantage of a higher penetration rate is misleading unless the overall advance rate can be significantly improved. Most mines realize that drilling is only one aspect of the mining cycle. Unless the entire mining cycle can be reduced sufficiently to provide an overall increase in performance, then the investment in hydraulic drilling equipment cannot usually be justified.

Most of the applications of hydraulic drilling equipment outside of the Elliot Lake camp have been applied to mine development work. Mining situations where drilling is continuous, such as uppers drilling in cut-and-fill stopes have been attempted, but without a great deal of success to date.

One recent trial confirmed the increase in penetration rate that results when hydraulic drills are used, but the overall footage drilled at the completion of the trial period was no greater than was already being accomplished by pneumatic drilling equipment. The main apparent performance limitation was not due to the hydraulic drill, but the difficulty in repositioning the drill carrier from hole to hole and when moving from place to place.

Many of the existing mine operators had considered converting to the use of hydraulic drills, but had elected to remain with existing drilling equipment for any number of reasons. Most frequently, mines were unable to find sufficient improvement in the overall mine cycle to justify the increased capital costs involved. Others reported that their ground was easy to drill with pneumatic drills and the degree of penetration improvement would not be that great. Other mines were reluctant to declare their warehouse stock as being obsolete and were reluctant to bear the added expense of retraining miners and mechanics.

In the case of new mines, however, it was noticed that with few exceptions, the use of hydraulic drill rigs had been selected over pneumatic drills. Mining methods and mine layouts had been developed to accommodate the operating features of hydraulic drills and other recent equipment developments. The costs associated with the necessary mine electrification, training of personnel and stocking of spare parts were included in the initial capital cost estimate and were justified on the basis of overall return based on a profitable mine operation.

The only exceptions to this trend for new mines were the situations of a few companies attempting to commence mine operations on a minimal capital budget. In these cases, equipment selection, as with other items, was made on the basis of lowest capital cost, irregardless of the operating cost disadvantages incurred. These types of situations are believed to be more a result of the speculative rationale for mine operation and not representative of the trend towards hydraulic drilling equipment.

As the suppliers of drilling systems mostly operate from a component-based system, it will be possible for mine operators to select from a wide assortment of drills and drilling accessories to satisfy the specific drilling requirements at their particular operation.

One major area not yet penetrated by hydraulic drilling equipment is the small captive cut-and-fill stoping drilling requirement presently being fulfilled by airleg and stoper drills. Mining companies have realized that economics do not favor methods that require overbreaking of the ore zone to accommodate large and efficient drilling equipment. As a result, miners are constrained to work with equipment that can be handled within the physical constraints of irregular and narrow orebodies.

A couple of European drill manufacturers have developed prototype hydraulic drills equivalent in size to the airlegs presently in use. These drills have not been accepted in the industry because they have proven too cumbersome to use. As it stands at the present time, the airleg drill market is price competitive, with drills being purchased primarily on the basis of lowest capital cost. Hydraulic drills would not offer sufficient performance advantages to justify the purchase of the more expensive drills.

The main reason for this is that the power of an airleg drill is at the extreme limit of what can be handled by manual effort. An hydraulic drill, even if lighter in weight, is too powerful to be manhandled by a single person. In addition, the need for extra hoses complicates the balancing of a hand-held hydraulic rock drill.

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Despite the capability of drill manufacturers to manufacture suitable hydraulic rockdrills, the difficulty of providing an adequate carrier at a reasonable price is the main impediment to the further use of this type of equipment. The smallest carrier presently available for use with small rockdrills costs in the range of $60,000 and is really a small jumbo.

Another difficulty faced by equipment developers is the problem of maintaining the balance of the equipment while in use over muckpiles in the stope. Most mines currently using equipment with narrow wheelbases have a recurring problem with tipping over their machinery causing personal injuries, as well as damage to the equipment.

Nevertheless, the potential does exist for hydraulically-powered equipment suited to the needs of small stoping methods. The mines with these types of orebodies will be in operation for the forseeable future and their need to improve manpower productivity and reduce the costs of production will remain as an incentive to the development of new and innovative equipment.

In the larger classes of hydraulic drilling equipment, it is commonly believed that trends will be to maintain the size of blastholes about the same as currently being used.

Experiments with larger blastholes, particularly in development headings, have not been universally successful. The evolution of button bits for smaller diameter blasthole drilling has made it possible to utilize the power of hydraulic rockdrills in small hole drilling.

A number of people have expressed interest in the development of electronic controls for hydraulic drills to eliminate the secondary hydraulic control circuit presently required on drill jumbos. It is thought that cost reduction could thereby be made with respect to all hydraulic drills and the automation of drill jumbos would be facilitated.

Few mine operators expressed serious interest in fully automated drill jumbos, as they considered any possible cost advantages very difficult to cost justify. It is expected that the various configurations of drilling units will continue to reflect a wide range of user opinions and preferences.

4.4 OTHER DEVELOPMENTS

The preceding sections have reviewed current mining equipment utilization trends based on the comments and opinions of mine operating staff from mines located across Canada. The following comments address emerging technologies that are on the threshold of being adopted for use within the mining industry. These emerging technologies are not widely understood by most mining personnel due to the lack of publicity. These promising developments in equipment technology do relate in various ways to the increased use of electricity in mining.

Continuous Loaders

A new version of a continuous loader for use in hard rock mines was developed by a Canadian contracting organization in 1982-83. These machines underwent extensive field trials and modifications and are now in production use in stope mucking applications.

Those people familiar with the application of these machines believe that a number of competing firms will be manufacturing various types of continuous loaders within the next few years. It is expected that an increasing proportion of ore removal from large blasthole stopes and stope drawpoints will be handled using these machines. They will be replacing diesel LHD units presently engaged in performing similar work.

The continuous loader as currently manufactured is an electrically powered, hydraulically operated machine. The use of this machine will serve to increase the utilization of electrical energy beyond present levels. It is expected that the increased availability of electrical power supplied to mucking locations will, in part, stimulate the use of additional types of electrically powered equipment.

Control Technology

Several mines are currently using some form of computer monitoring and controlling equipment to improve supervisory control over mining equipment and operations. Some mines are using rudimentary systems, while others have installed more elaborate equipment to perform a variety of tasks.

The effective use of this technology is only possible with a more extensive use of electrification than is currently practiced at most Canadian mines. As mine operators and management begin to realize the benefits that can be obtained through the use of control technology, the incentive to install and use more electrically operated equipment will be increased. The costs associated with electronic control devices are expected to decline as a result of wide application to other industries outside of mining.

Exotic Drilling Techniques

The use of laser drilling and the fracturing of rock by direct application of electrical energy is not seen as being of practical value by any of the mining personnel interviewed as part of this project. The general concensus was that the greatest gains in productivity in the near term will be attained by the continued adaptation of existing mining methods and techniques, rather than through the introduction of exotic electrically powered devices.

5.0 INFLUENCE ON MINE DESIGN

The present level of mining machinery technology available to Canadian mine operators provides the capability to excavate rock in almost any type of ground conditions. The thrust of equipment development over recent decades has been directed towards the mining of orebodies not considered to be economically or technically feasible by older methods.

Concurrently, the scale of underground mining equipment has increased dramatically in order to provide increased manpower productivities and reduce overall mining costs. Stoping dimensions were increased to allow economies of scale made possible by the use of the larger mining machinery.

All of these changes in mining equipment and mine design were required to sustain the mining industry through buoyant economic cycles when metal prices were determined by a high demand for metal output. During this period of time, the ability to produce large quantities of metal at reasonable costs was the driving force behind developments in mining technology.

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The situation faced by Canadian mines at the present time is vastly different than that of a few years ago. The demand for high levels of metal production is considerably diminished and the principal objective of most operators is to reduce their costs of production as a matter of survival.

The equipment that fulfilled the needs of the Canadian mining industry in past years is not necessarily the same equipment needed to ensure the continued survival of our mining operations in the future. The emphasis has shifted towards the development of mining methods and techniques that will enable Canadian mines to become the lowest cost producers of their metal products.

The two principal objectives of the most progressive mine planners is to further develop existing mining technologies so as to lower mining costs by:

a) Drastically reducing manpower requirements;

b) Significantly increasing stoping production rates.

It is believed that these objectives will only be achieved by the substitution of people by machines to the maximum extent possible. The extent to which these objectives will be fulfilled will depend to a great extent on the ability of mining companies to radically change the way in which mines are developed and operated.

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From the lessons of the 1970's and early 1980's, the industry has grown suspicious of the universal application of large equipment sizes and the large excavations required for the safe operation of this machinery. It is being realized that small openings and the use of captive equipment that enable a minimum of overbreak beyond the economic limits of the ore zones being mined are more relevant to the requirements of developing mines in the late 1980's. The remaining working effort can then be concentrated in activities directly related to ore breaking and removal, rather than being diluted by the additional service requirements associated with large scale equipment and excavations.

The most critical need is for the development of machinery that can be operated within the constraints of narrow orebodies and still provide working capabilities beyond the present limits of existing equipment. The use of pneumatically powered equipment has long ago reached it's maximum level of efficiency. The only apparent alternative is in the development of electric, or electric hydraulic equipment in order to utilize power sources that can transmit and exert more concentrated forms of energy than is the case with pneumatic tools.

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It is recognized that stope openings can only achieve certain finite sizes, dependent primarily on orebody configuration and ground conditions. Also, it is difficult to forsee altering the drill-blast-muck stope cycle in the near future. This leads to the conclusion that existing methods of ore breaking and transportation will remain in place, but modified to enhance increased performance and reduced costs.

The most significant obstacle that limits the implementation of increased use of electrical energy within traditional mining situations is the lack of awareness on the part of mine designers as to the mining machinery options that are, or may soon be, available to them. As a result of this lack of awareness, mines are designed to accommodate existing equipment methodologies and thereby restricts the capability to incorporate new innovations for reasons mentioned earlier in this report.

If Canadian mines are to break from this cycle of perpetuation of existing equipment, mine designers must have a clearer understanding as to the direction that new equipment innovations will take. Clearly, increased electrification and increased mechanization are the emerging trends. Realization of these facts will ultimately stimulate mine designers to focus on ways to apply equipment to their site specific conditions.

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The implementation of technology in mining is progressive in nature. That is, different levels of mining technology are applicable to different mining situations. For this reason, a progressively-oriented mining team can adapt to innovations more readily than can a group that has less experience with some of the newer forms of equipment.

It is believed that, as in many situations, a basic proficiency must be achieved in mastering fundamental forms of machinery before a group of individuals is prepared to move on to more sophisticated versions of the same type of machinery. Therefore, it is not sufficient to concentrate strictly on the development of new and innovative machinery, but efforts must also be expended to transfer appropriate technological developments to mines that are prepared to take the next step beyond their present generation of mining machinery.

Conceptually, hard rock mines must move in the same directions as have the coal mines in utilizing hydraulically powered machinery, and the potash mines in utilizing electrically powered machinery. In detailed form, however, the mining equipment must look and function similar to the pneumatic tools currently in use within the hard rock mines.

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The safety aspects of increased electrification are well understood and practiced within the mining industry, particularly within the coal and potash mines. The personnel associated with the hard rock fraternity are believed to be at least equally capable of using the same power sources safely and productively. The myth concerning the inherent safety of pneumatically powered tools has been greatly overstated, as have the perceived difficulties regarding the deployment of electric power cables in underground mines.

The mines inspectorate across Canada have adequate regulations and technical expertise to ensure that new electrical and hydraulics-based technologies meet acceptable levels of fail-safe performance. No modifications or extensive revisions are anticipated to any mining regulations to authorize the increased utilization of electricity in underground workings.

The major challenge to equipment designers will be to adapt machinery developments from other industries for the benefit of mining machinery, in order to reduce the capital and operating costs of new mining machinery and to ensure that the increased performance objectives can be attained in the existing underground environment.

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It is anticipated that the objectives of reduced manpower levels and increased production per active stoping area can only be achieved through mechanization and increasing the number of operating hours per week relative to current practices. It is widely known that the amount of 'face time' spent by today's mining crews is only 50-60 percent of each working shift, with the balance occupied by travel, meals and other ancillary tasks. This is compounded by working from 5-10 shifts per week in each active stope.

Increased mechanization and increased utilization of electric power do not have to result in productivity increases per unit of time, provided that the number of time units can be significantly increased. The potential of increasing the active 'face time' from 40 hours per week to 168 hours per week should at least yield a 50 percent increase in productivity, even when allowing for lower machine performance per unit of time.

The key to this increase in time utilization is not changes in mining methods 'per se', but increased utilization of computer monitoring and control equipment to enable the continued operation of mining machinery without an operator being in attendance. Although the full realization of this objective is some time in the future, the initial steps must be taken soon.